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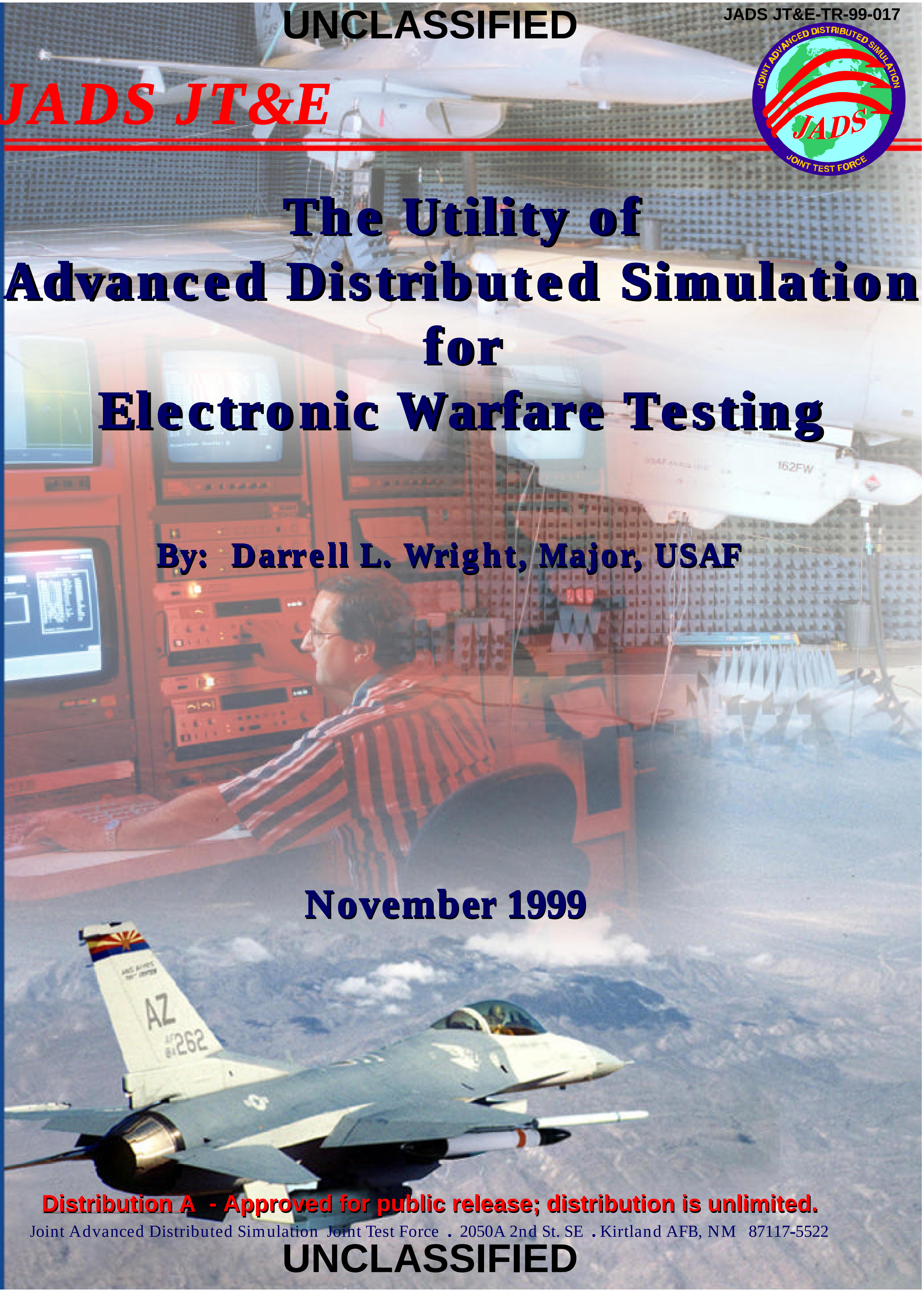

JADS JT&E

The Utility of Advanced Distributed Simulation for Electronic Warfare Testing

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FOREWORD

In the early nineties, the proposition that advanced distributed simulation (ADS) was the wave of the future for test and evaluation (T&E) was advanced. Reaction was mixed. At one end of the spectrum were people who believed the need for live testing would fade away, and at the other end were people who scoffed at the notion that ADS had any utility at all for testers. At the policy-making level, expectations were high and skepticism was subdued. At the implementation level, expectations were low and skepticism was high.

The Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E) program was chartered in October 1994 to conduct an objective assessment of the worth of ADS for support of T&E. The joint test force (JTF) conducted tests in three functional areas: precision guided munitions (PGMs); command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR); and electronic warfare (EW). While the JTF effort was resource constrained, its results have broad relevance. Each of the test areas is documented in executive-level utility reports. This report addresses the utility of ADS in EW testing.

This report suggests that there is a range of utility for ADS in EW testing. The greatest utility is expected in systems of systems testing such as testing electronic support systems. These systems consist of multiple C4ISR-based EW platforms, rely on information systems technology, and are relatively immune to the effects of latency and data loss that are inherent in ADS architectures. Integrated EW systems are expected to benefit from ADS as well, especially where a single facility is unable to test all the EW functions simultaneously in a single test event. Transporting the system integration laboratory from the contractor's facility to a government test facility is impractical for highly integrated EW systems. Federated systems or single function EW systems are generally adequately tested using traditional test methods. Use of ADS-enhanced testing on open air ranges may be limited by the ability to inject the synthetic environment into the platform.

We believe the intelligent application of ADS technology for testing EW systems can provide benefits in an affordable manner. EW program and test managers should familiarize themselves with ADS and routinely consider its use in their deliberations and planning activities. It is our hope that ADS will be treated as a readily available tool. While the use of ADS will not make sense in every case, there are many cases where it not only makes sense, but it may offer the only practical approach to realistic and rigorous testing of EW integrated systems and systems of systems. We will support and assist program and system managers who see applications for ADS in their test events and programs.

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Executive Summary

1.0 Overview

The Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E) was chartered by the Deputy Director, Test, Systems Engineering and Evaluation (Test and Evaluation), Office of the Secretary of Defense (OSD) (Acquisition and Technology) in October 1994 to investigate the utility of advanced distributed simulation (ADS)[1] technologies for support of test and evaluation (T&E). The JADS program is Air Force led with Navy and Army participation and is scheduled to end in March 2000. This report addresses the third of three separate JADS tests, the Electronic Warfare (EW) Test, which was completed in April 1999.

The EW Test evaluated the utility of ADS to support EW T&E. While the test used several efforts to examine ADS-based T&E, the cornerstone effort was a series of traditional and ADS-based test events using an airborne self-protection jammer. This effort was called the self-protection jammer (SPJ) test. The SPJ test defined a simple, repeatable test scenario. The scenario was executed in three traditional test environments to create a data baseline. The test scenario was then executed in two ADS-enhanced test environments. The first ADS-based test event used a real-time digital system model (DSM) interacting with manned threat simulators at the Air Force Electronic Warfare Environment Simulator (AFEWES) facility. The second ADS-based test used the SPJ installed on an F-16 suspended in the anechoic chamber at the Navy's Air Combat Environment Test and Evaluation Facility (ACETEF). The data from all tests were statistically compared in an attempt to quantify the impacts of ADS.

The other efforts used by JADS to examine the utility of ADS to support EW T&E:

1) The OSD CROSSBOW Committee-sponsored Threat Simulator Linking Activity (TSLA) effort,
2) The Defense Modeling and Simulation Organization (DMSO)-sponsored High Level Architecture (HLA) Engineering Protofederation (EPF) effort, and
3) The Army's Advanced Distributed Electronic Warfare System (ADEWS) development effort.

Each of these efforts added to the SPJ test experience to provide JADS with a broader understanding of the utility of ADS to EW T&E.

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[1] Distributed simulation-based testing can be accomplished locally as is practiced today at hardware-in-the-loop (HITL) facilities and installed systems test facilities (ISTFs) such as the Air Force Electronic Warfare Environment Simulator (AFEWES) and the Navy's Air Combat Environment Test and Evaluation Facility (ACETEF). Distributed simulation-based testing can also be geographically distributed. For the purpose of this report, ADS is defined as a networking method that permits the linking of constructive simulations (digital computer models), virtual simulations (man-in-the-loop or hardware-in-the-loop simulators), and live players located at distributed locations into a single test environment/scenario.

2.0 EW Test Results and Conclusions

Within the confines of the SPJ test data, JADS concluded that ADS architectures that allow the capabilities of geographically separated facilities to be combined to create a realistic test environment for EW devices can be designed. This allows the same test environment to be used for system under test (SUT) representations ranging from DSMs to operational equipment. Testing in a common ADS-based environment represents a significant departure from the traditional sequential EW test process.

Key results

- Designing ADS architectures requires a close team comprised of several technical experts spanning several disciplines directed by a system integrator.
- The architecture produced valid results for both the DSM and actual jammer hardware.
- Latency within the closed-loop interaction was aggressively managed, and JADS was able to meet its objective for more than 95% of the runs.
- The HLA appears to be a feasible method for linking simulations for T&E. It is appropriate to use HLA to link to other HLA-compliant simulations/simulators, but the T&E community should not view it as the only solution to consider in designing distributed tests. The selection of linking technologies should be driven by the test objectives. In many cases, special data links or tactical communications links may be more appropriate and desired for a specific test objective.
- Two of the eleven EW test facilities surveyed in 1996 as part of the TSLA effort that were appropriate for ADS-based testing have been closed. While this is a significant erosion in the infrastructure needed to design and execute ADS-based tests, it already limits the traditional EW testing process.

3.0 Observations for EW T&E

JADS assessment, based on the different EW Test efforts, is that ADS has varying levels of utility for EW T&E. These levels of utility depend on the nature of the EW device being tested and the availability of suitable test facilities. Single function EW devices and federated EW systems are expected to benefit least from an ADS-enhanced test process. Only radio frequency jammers may see sufficient benefit to outweigh the additional cost of an ADS-enhanced test process. Integrated EW systems may see significant benefits where a single test facility is not capable of providing all the stimulation (including the closed-loop SUT versus manned threat interaction for systems that include radio frequency [RF] jammers) needed to simultaneously test all the particular integrated EW system's functions. Systems of systems testing such as that required for electronic support (ES) systems should see significant benefits in ADS-based testing.

1.0 Purpose And Background

1.1 Report Purpose

This report summarizes the assessment of the utility of advanced distributed simulation[2] (ADS) for the test and evaluation (T&E) of electronic warfare (EW) systems. This assessment was based on the results and lessons learned from the Joint Advanced Distributed Simulation (JADS) EW Test along with results from other related efforts.

The assessment presented in this report provides general insight into the implementation of ADS-based testing for EW systems. More detailed guidelines for linking specific classes of systems for EW testing can be found in the Threat Simulator Linking Activity (TSLA) specification series and in the JADS special reports.

1.2 JADS Overview

The JADS Joint Test and Evaluation (JT&E) program is an Office of the Secretary of Defense (OSD)-sponsored joint service effort designed to determine how well an emerging technology, advanced distributed simulation (ADS), can support test and evaluation activities. The Department of Defense (DoD) has always used rapidly evolving information systems technology to support its needs. Early efforts were sharply focused on training applications and evolved from the Simulation Network (SIMNET) program managed by the Advanced Research Projects Agency (ARPA) and the Army. Conceptually, the early projects were directed toward linking training simulators with human operators at distributed geographical sites in a common virtual environment. The players interacted with one another in this common environment in near real time. Over the years SIMNET has evolved into a technology implementation that is more flexible and robust and includes different types of simulators with different levels of fidelity. (Reference 4) The capabilities spawned by the SIMNET evolution are now called distributed interactive simulation (DIS) and are documented in Institute of Electrical and Electronics Engineers (IEEE) Standard 1278. The high level architecture (HLA) is the latest step in the effort to enable DoD simulations to connect with one another in a common virtual environment. In 1996, Dr. Paul Kaminski, Undersecretary of Defense (Acquisition and Technology), directed DoD to make all simulations HLA compliant, although it is not yet an approved IEEE standard. (Appendix B) HLA consists of an interface specification, implementation rules, and tools to help users create synthetic environments in which live, virtual, and constructive (synthetic) players can interact. The centerpiece of HLA is the runtime infrastructure (RTI), a distributed software application that handles all the simulation-to-simulation communication. Because of widespread interest in using

[2] Distributed simulation-based testing can be accomplished locally as is practiced today at hardware-in-the-loop (HITL) facilities and installed systems test facilities (ISTFs) such as the Air Force Electronic Warfare Environment Simulator (AFEWES) and the Navy's Air Combat Environment Test and Evaluation Facility (ACETEF). Distributed simulation-based testing can also be geographically distributed. For the purpose of this report, ADS is defined as a networking method that permits the linking of constructive simulations (digital computer models), virtual simulations (man-in-the-loop or hardware-in-the-loop simulators), and live players located at distributed locations into a single test environment/scenario.

synthetic environments (and the technology and standards needed to create them) to support test and evaluation, the Air Force Operational Test and Evaluation Center (AFOTEC) felt that a JT&E program could serve as an exploratory vehicle. Accordingly, the JADS JT&E program was nominated. Interest was shared by both the developmental and operational test communities. The services concurred in the need for rigorous examination of the use of synthetic environment technology, and the Deputy Director, Test, Systems Engineering and Evaluation (Test and Evaluation), OSD (Acquisition and Technology) chartered JADS as a joint test program in October 1994. (Reference 1) JADS was chartered to investigate the utility of ADS for both developmental test and evaluation (DT&E) and operational test and evaluation (OT&E). JADS was tasked to investigate the utility of ADS, including DIS and HLA, for T&E; to identify the critical concerns, constraints, and methodologies when using ADS for T&E; and finally, to identify the requirements that must be introduced in ADS systems if they are to support a more complete T&E capability in the future.

JADS investigated ADS applications in three slices of the T&E spectrum: the System Integration Test (SIT) explored ADS support of air-to-air missile testing; the End-to-End (ETE) Test investigated ADS support for command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) testing; and the EW Test examined ADS support for EW testing. The JADS Joint Test Force (JTF) was also chartered to observe or to participate at a modest level in ADS activities sponsored and conducted by other agencies in an effort to broaden conclusions developed in the three dedicated test areas.

2.0 Supporting Activities and Results

The EW Test was built on four discreet efforts. Each effort was intended to provide insight into the limitations of technology supporting ADS, the fundamental requirements that ADS architectures must support for EW T&E, and the application of ADS to EW testing. These efforts were

1) JADS-sponsored and managed self-protection jammer test,
2) OSD CROSSBOW Committee-sponsored Threat Simulator Linking Activity,
3) Defense Modeling and Simulation Organization (DMSO)-sponsored High Level Architecture (HLA) Engineering Protofederation (EPF), and
4) Army-sponsored Advanced Distributed Electronic Warfare System (ADEWS) development program.

Each effort is described below and results are discussed at the end of this section.

2.1 EW Self-Protection Jammer (SPJ) Test

The EW SPJ test directly evaluated the utility of ADS to support testing of EW systems using the ALQ-131 as one component of a representative EW test environment. The intent was to recreate selected test events in the development cycle of an airborne self-protection jammer to directly investigate the ability of ADS to address perceived shortfalls in the EW test process as articulated in *A Description of the DoD Test and Evaluation Process for Electronic Warfare Systems, Revision 2,* dated 31 July 18, 1996, prepared by the Director, Test, Systems Engineering and Evaluation.

The SPJ test consisted of three separate test phases. The first test phase was a series of traditional tests designed to collect a baseline set of data. During this test series, JADS used the Western Test Range to accomplish 14.4 hours of open air range (OAR) testing, the Air Force Electronic Warfare Evaluation Simulator (AFEWES) hardware-in-the-loop (HITL) facility, and a system integration laboratory (SIL) facility. The collected data were used to calculate ten traditional EW measures of performance (MOPS). These MOPS formed the baseline data set.

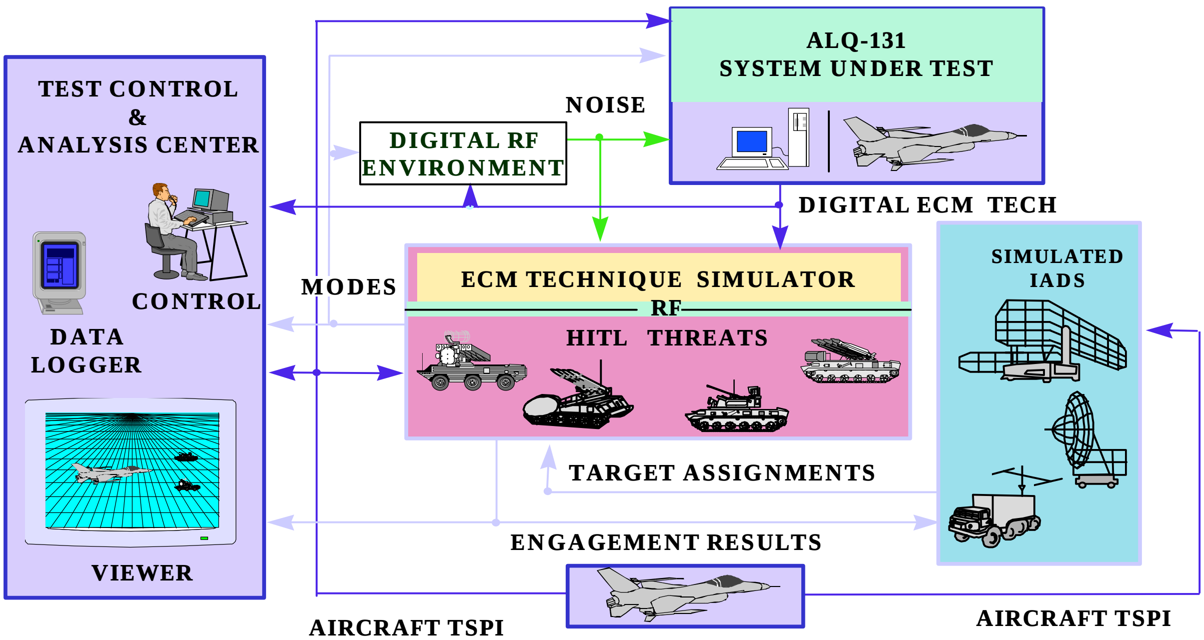
The second and third SPJ test phases recreated the baseline test environment using an ADS architecture. The architecture used remained constant while the representation of the SPJ changed. The intent of changing the SPJ representation was to mimic testing in two different SPJ development phases. Phase 2 used a real-time digital system model (DSM). Phase 3 used the ALQ-131 mounted on the host aircraft that was suspended in an installed systems test facility (ISTF). In both Phase 2 and Phase 3, the same EW data were collected and used to calculate the same ten MOPs calculated in Phase 1. The Phase 1 baseline was statistically compared to the results of each of the ADS-based test phases to quantify impacts on the EW MOPs caused by using ADS to create a virtual test environment. Phase 2 and Phase 3 are discussed below.

2.1.1 Phase 2 Digital System Model Test

JADS wanted to demonstrate that ADS could be used to create a common test environment that could potentially be used throughout system under test (SUT) development. The first representation of the SUT according to the DoD EW test process is the DSM.

The test process discusses using DSMs of the SUT running interactively with DSMs of "host platforms, other friendly players, the combat environment, and threat systems" to provide cost effective T&E. (Reference 12, Paragraph 2.4.2.2.7.1) The Phase 2 DSM test represented a test early in the SPJ development that is an extension to the current EW test process. The test process extension embodied in the Phase 2 test used the DSM interacting with real humans instead of models to gain an early understanding of system effectiveness against human operators. In the JADS test, the DSM, hosted at the Air Combat Environment Test and Evaluation Facility (ACETEF), Patuxent River Naval Air Station, Maryland, interacted in a closed-loop with four manned threat simulators in the AFEWES facility, Fort Worth, Texas. Test control was performed at the JADS facility in Albuquerque, New Mexico.

The DSM test used a distributed test architecture to recreate the baseline OAR and HITL environments. The architecture was built using the HLA interface and RTI, HLA rules, and the available HLA tools. The architecture linked JADS in Albuquerque, AFEWES in Fort Worth, and ACETEF in Patuxent River. AFEWES provided the threats. The DSM was hosted at ACETEF. All other players were hosted at JADS. Figure 1 shows each of the federates and the key messages each sent and received.



ECM = electronic countermeasures
RF = radio frequency

IADS = Integrated Air Defense System
TSPI = time-space-position information

Figure 1. EW Test Federates

The architecture did not pass radio frequency (RF) waveforms across the T-1 communication lines. Instead, operator actions were translated into mode change messages defined in the JADS EW Test interface control document (ICD). The AFEWES threats operate in RF; however, the DSM is obviously not capable of producing RF. Therefore, JADS used equipment at AFEWES, the JammEr Technique Simulator (JETS), to generate the jamming waveforms based on commands from the DSM. JADS had allocated 500 milliseconds for latency in the threat/jammer closed-loop interactions. In other words, JADS wanted no more than 250 milliseconds to elapse from the time an operator's actions changed the state of the threat until the mode change message arrived at the DSM and no more than 250 milliseconds from the time the DSM issued the command to jam until RF energy came from the JETS at AFEWES.

The DSM test completed 246 runs. The DSM data were evaluated by subject matter experts and deemed valid for 245 runs. The MOPs did not show a consistent degree of correlation with either the OAR or HITL data; however, this was not due to ADS effects. Operator response differences at both the OAR and HITL and threat differences between AFEWES and the OAR were the primary variance sources. The statistical tests JADS used also contributed to the lack of correlation.

This does not imply that ADS had no effect on the test. Bursts of data dropouts in the time-space-position information (TSPI) that provided the aircraft/jammer location were generally handled by dead reckoning algorithms in the DSM and at AFEWES. The algorithms supplied an estimated aircraft position until an update was received. At the point TSPI data were again received, the aircraft was moved to the known valid position. In one instance, the move induced a tracking error spike greater than one degree in azimuth and elevation while a missile was in flight. The missile was not able to recover, resulting in an invalid miss distance. This was observed in real time during the test execution, and the data were scanned for similar occurrences.

Other potential ADS effects such as latency and out-of-order data were addressed in the design of the architecture. Only eight of the completed runs exhibited latency above our design goal for the closed-loop interaction. Out-of-order data were observed, but all EW MOP calculations were based on the time the data were created, not when they were received.

2.1.2 Phase 3 Installed Systems Test Facility (ISTF) Test

The Phase 3 ISTF test represented another extension to the OSD EW test process that would occur very late in the SPJ development. In this case, the extension was closed-loop testing in an ISTF facility. ISTF test events use "simulated and stimulated inputs" to "provide critical information regarding integrated system performance." (Reference 12, Paragraph 2.4.2.2.5) However, these simulated inputs are limited to those that the ISTF is capable of generating. In the Phase 3 ISTF test, JADS used the same manned threat simulators that were used in the Phase 2 DSM test. The ISTF at ACETEF did not have manned threat simulators for these threats. JADS used ADS to create a closed-loop test capability that allowed JADS to collect and evaluate jammer effectiveness at a facility that had no manned closed-loop threat simulators for the threats of interest.

JADS used the architecture created for the Phase 2 DSM test to allow the real jammer to interact with the AFEWES threats. The actual jammer used on the OAR was mounted on an aircraft and both were suspended in the anechoic facility at ACETEF. The aircraft electronics systems including the fire control radar were allowed to radiate in the chamber to simulate electromagnetic interference (EMI)/compatibility (EMC) testing. At the same time, the threat signals were injected into the jammer and the jammer responses were radiated into the chamber. This showed that it may be possible to conduct EMI/EMC testing in conjunction with jammer effectiveness testing, providing a more robust test environment.

During this test phase, we made excursions to the reference test condition to see if there were any readily apparent limitations in our architecture. During these runs, ACETEF used the Synthetic Warfare Environment Generator (SWEG) model to add two low fidelity threats into the ACETEF environment. This was a simple demonstration of how threats could be added into a test environment to increase the threat density.

Again, the architecture did not pass RF waveforms across the T-1 communication lines. This time the pod had to receive RF energy, so JADS used equipment at ACETEF, the Advanced Tactical Electronic Warfare Environment Simulator (ATEWES), to create the RF energy based on

AFEWES operator actions. The 500 millisecond latency requirement did not change. However, more equipment at ACETEF was involved to connect the actual jammer to the virtual environment than was needed to connect the DSM in Phase 2.

The ISTF test completed 223 runs. The ISTF data were evaluated by subject matter experts and deemed valid for all 223 runs. The MOPs did not show a consistent degree of correlation with either the OAR or HITL data. Again this was not due to ADS effects. Operator response differences (at both the OAR and HITL) and threat differences (between AFEWES and the OAR) were the primary variance sources. The statistical tests themselves again contributed to the lack of correlation. However, the MOPs showed a tendency to correlate better with Phase 2 data than with any other data set.

Bursts of data dropouts in the TSPI were not seen and latency improved overall. A new effect was seen in this test. We had to abort two runs when the time synchronization hardware and software failed to keep AFEWES synchronized.

Other potential ADS effects such as latency and out-of-order data were addressed in the design of the architecture. Only one of the completed runs exhibited latency above our design goal for the closed-loop interaction. Out-of-order data were observed, but all EW MOP calculations were based on the time the data were created, not when they were received.

2.2 Threat Simulator Linking Activity

TSLA was an OSD CROSSBOW Committee-sponsored study to investigate and document the requirements and potential design for linking existing EW test resources. This study was accomplished in three phases. The first phase investigated previous and ongoing efforts to use ADS in EW T&E facilities. Phase 2 reported on network requirements to link test facilities. Phase 3 produced preliminary system/segment specifications, software design specifications and interface design specifications for the ADS network. This effort was completed in 1997 and the results can be obtained from CROSSBOW. (References 4, 5, 6, 7, 8)

2.3 HLA Engineering Protofederation (EPF)

In 1996, DMSO implemented a series of fast-paced development and prototyping efforts. JADS monitored the EPF that evaluated HLA in an EW T&E environment. This effort linked facilities at Patuxent River, Maryland; Wright-Patterson Air Force Base, Ohio; Buffalo, New York; Fort Worth, Texas; and Huntsville, Alabama. The purpose was to create a realistic exercise designed to stress the HLA federation test environment to realistic T&E levels. The results are documented in evaluation reports produced by MITRE and by ACETEF. (References 13, 14)

2.4 Advanced Distributed Electronic Warfare System (ADEWS)

ADEWS is an Army-sponsored program to test communications systems using an ADS-based jamming system. JADS monitored the proof-of-principle phase in which the Army completed a field demonstration of their virtual jamming system. This system is comprised of a Covert Remote Electronic Warfare Simulator (CREWS) transmitter mounted on the victim communications equipment and connected between the antenna and the equipment. The CREWS transmitter is controlled by a jammer simulator that uses RF tones to communicate wave-form and transmitted power to each device. Received power is determined within the CREWS device by calculating the distance and terrain effects between the jammer and the victim.

2.5 Summary of Results

2.5.1 SPJ Test Results

The key results from the SPJ testing were as follows.

- Designing ADS architectures requires a close team comprised of several technical experts spanning several disciplines directed by a system integrator. Expertise required includes SUT, test facility, instrumentation, data collection and analysis, wide area computer communications, local area computer communications, computer operating system and communications protocol, and RTI (or other linking technology).
- The architecture produced valid[3] results for both the DSM and actual jammer hardware. Few ADS-induced errors were observed. These were easily identified and the data were removed from the valid data set.
- Latency within the closed-loop interaction was aggressively managed, and JADS was able to meet its objective for more than 95% of the runs. Variance in latency may be more problematic for some test designs. JADS time stamped each message before transmission and used this time stamp for analysis instead of the time of receipt.
- Data loss and out-of-order data are ADS effects that must be addressed in the architecture design. Assigning unique message numbers and the time stamps applied before transmission to detect and deal with data loss and out-of-order data was effective.
  - Bursts of data loss were seen in the TSPI data stream in the Phase 2 DSM architecture; however, the losses generally did not affect the runs because both the DSM and AFEWES used dead reckoning algorithms. This allowed both players to estimate the SUT position until the TSPI resumed.
  - These losses were still less than 1% of all the messages transmitted. The Phase 3 ISTF architecture used a later RTI release and minor changes were made in the network hardware. The bursts of data loss were not seen in the TSPI data stream in Phase 3.
- The ADS architecture provided ample bandwidth.

[3] Data validity was determined by subject matter experts. The expert panel determined that the data were consistent with the expected results from traditional tests using the same reference test condition. Direct statistical comparison was inconclusive primarily because of differences in operator skill levels.

– Network component failures interrupted testing three times for less than 15 minutes total test time. Computer crashes at JADS and hardware failures within ACETEF and AFEWES were responsible for most of the aborted runs and lost test time, respectively.

2.5.2 Threat Simulator Linking Activity Results

– The SPJ test validated key aspects of the TSLA specification set. Validation included message sizes, data packing in message structures for increased efficiency, and instrumentation required to accomplish ADS testing.
– The TSLA resources survey accomplished in 1996 examined different aspects of eleven EW test facilities to support ADS for testing EW systems. Two of these facilities no longer do EW testing; one was closed and relocated, and one is planned to be closed and relocated. The Air Force has been impacted the most by these changes. The Air Force-owned facilities that were not affected by the changes are the least experienced in ADS.

2.5.3 HLA Engineering Protofederation Results

– JADS used the EPF ICD as starting point for developing the JADS EW Test ICD.
– The HLA appears to be a feasible method for linking simulations for T&E. Direct results from the EPF effort provided JADS with a baseline for measuring how quickly HLA is maturing. It is currently immature; however, it is evolving rapidly. The pace of change coupled with its immaturity made it difficult to use.
– The runtime infrastructure (RTI) is also immature although it has significantly improved. The SPJ test results indicate that the current DMSO-provided RTI effectively moves data, but the lack of documentation and the latency variation added by the RTI are issues. The runtime infrastructure improved throughout the JADS SPJ test. JADS used a later version of the RTI in the Phase 3 ISTF test and saw improvements in latency performance and a significant reduction in lost data.
• It is appropriate to use HLA to link to other HLA-compliant simulations/simulators, but the T&E community should not view it as the only solution to consider in designing distributed tests. Facilities such as AFEWES and ACETEF have built HLA-compliant interfaces, but communications between resources within their facilities are done using whatever approach makes the most sense. The selection of linking technologies should be driven by the test objectives. In many cases, special data links or tactical communications links may be more appropriate and desired for a specific test objective.

2.5.4 Advanced Distributed Electronic Warfare System Results

– The proof of concept was successful and further developments are being pursued. Expansion of the current CREWS device to test global positioning system (GPS) jamming is expected to be funded in fiscal year (FY) 00.

3.0 Overall ADS Utility Assessment

3.1 JADS Issues

The JADS JT&E program was chartered to investigate the utility of ADS for both DT&E and OT&E. The charter letter identifies three issues to be addressed.

- Investigate the present utility of ADS, including DIS for T&E. The utility assessment includes evaluating the validity of data from tests using ADS and the benefits of using ADS in T&E.
- Identify the critical constraints, concerns, and methodologies when using ADS for T&E.
- Identify the requirements that must be introduced into ADS systems if they are to support a more complete T&E in the future.

The ability of ADS to support EW T&E will be assessed in terms of these issues.

3.2 General Utility of ADS for Electronic Warfare T&E

3.2.1 General Utility Assessment

ADS has utility for EW DT&E and OT&E because ADS-supported tests can provide valid EW system performance evaluations in a number of areas addressed by both DT&E and OT&E (see section 3.2.3), and because there are benefits to using ADS for EW T&E (see section 3.2.2). The application of ADS for a specific EW system (see section 4.2) depends on (1) the test objectives, (2) the characteristics of the EW system, (3) the availability of EW DSMs, sensor stimulators, HITL or OAR manned threat simulators, and (4) the details of the test scenario. Simple guidelines for designing an architecture for ADS-supported testing are contained in Appendix C.

3.2.2 General ADS Benefits

ADS allows the test designer to break the traditional mold of stovepipe sequential testing. The following are the general benefits ADS brings to EW system development and EW T&E.

- ADS supports more robust validation of DSMs by allowing DSMs to interact with manned simulators.
  - This provides more confidence in model-on-model results.
- ADS extends the use of secure test environments beyond the boundary of a single facility.
- ADS allows the use of common threats and environments across development phases.
  - Common threats and environments promote the one-to-one comparison of results across development phases.
  - Common threats and environments couple well with the Navy's concept of scenario-driven T&E.
- ADS allows reactive scenarios to be used across all development phases.
- ADS allows operationally relevant testing to occur earlier in development.

- ADS facilitates testing integrated EW systems and systems of systems.
  - ADS allows direct measurement of mission-level MOPs and measures of effectiveness (MOEs).
- ADS allows tests to address broader testing objectives (e.g., mission level) beyond the capability of a single facility.

3.2.3 General Role of ADS in EW T&E

ADS allows the test designer to construct tests that address objectives beyond the capability of a single facility. While connecting facilities can be beneficial, not all EW testing requires the use of ADS. Single device and federated systems testing are generally adequately supported by the sequential facility testing paradigm (the progression from DSM to SIL, SIL to HITL, HITL to ISTF, ISTF to OAR) recommended in the DoD EW test process description. Testing integrated EW systems and systems of systems does not readily conform to the sequential facility testing paradigm. The requirement for testing these systems is to create an operationally realistic single environment in which all integrated EW functions, including closed-loop interaction with manned threat simulators, are simultaneously tested while interacting with the host platform, the host platform operator(s), and the appropriate blue and red players. Any less stringent test increases the risk of fielding a flawed system. Highly integrated avionics systems such as the F-22 share resources. The only way to fully understand the effects of resource sharing is to test all system functions at the same time in the operationally realistic single environment described above.

To be tested, all integrated EW systems may not require ADS. If a single facility is capable of providing all the stimulation (including the closed-loop SUT versus manned threat interaction for systems that include RF jammers) for the particular integrated EW system, then ADS is not needed. However, if no facility exists, ADS offers an alternative to potentially expensive facility modifications or expansion. The development and integration of distributed test facilities (such as AFEWES and ACETEF) capable of simultaneous EW sensors stimulation and closed-loop threat interaction presents the facility designer with the same problems of latency, data loss, and out-of-order data that confront the ADS architecture designer.

Systems of systems testing is not likely to be practical or affordable in a single facility or on a single OAR. Simple cooperative jamming tests against single threats can be accomplished using the sequential testing methods described in the OSD EW test process. More complicated systems of systems testing on an OAR is constrained by the limitations the single facility or the limitations of the range selected and the cost of bringing the required platforms together for the test event. The JADS End-to-End Test was a command, control, communications, computers and intelligence (C4I) systems of systems test using the Joint Surveillance Target Attack Radar System (Joint STARS). JADS concluded "ADS has great potential as a C4ISR testing tool and provides a viable means of conducting realistic mission-level evaluations." (Reference 3)

Some OAR limitations can be removed and OAR environments can be extended through the use of ADS. The ADEWS program demonstrated that ADS allows realistic large-scale communications jamming without impacting commercial communications. The JADS EW Test investigated and concluded that ADS can be used to link manned simulators of semi-active threats on the OAR to HITL-based seeker simulators. This arrangement allows the seeker simulator to use the OAR track loop errors while it operates in a realistic (correct Doppler) RF environment. (The architecture needed to accomplish this is similar to the SIT live fly architecture.) By using real-time links, the OAR can provide real-time, high fidelity, semi-active missile flyouts complete with OAR tracking loop error effects. (Reference 9)

3.3 Critical Constraints, Concerns, and Methodologies for EW T&E

3.3.1 Geographically Distributed Interactive Simulation Infrastructure Limitations

Certain constraints limit the applicability of ADS to EW T&E. Some of these constraints are due to the DSMs, HITL facilities, ISTF facilities, or OARs and are common constraints for both ADS-supported testing and testing using the OSD EW test process. Other constraints result from linking requirements and are related to ADS implementation. The constraints are summarized as follows.

- **DSM Constraints**

  – DSMs must work in real time to usefully link with manned threat simulators, manned operator stations, or other real-time simulations of blue or red players. Real-time execution is not a requirement for HLA or Joint Modeling and Simulation System (JMASS) compliance. Unlike HLA, JMASS is not currently capable of real-time execution.

- **HITL, ISTF and OAR Constraints**

  – While ADS provides the ability to use resources across facilities, the fidelity of the resulting environment is limited by the fidelity of the test infrastructure to create each piece of the environment. Specifically, the fidelity of the synthetically generated signals is limited to the capability of the simulator/stimulator connected to the SUT, threat, or other players in the scenario. (This is not unique to ADS test environments. The fidelity of the environment is always a test constraint and must be addressed in the test design analysis as well as the post-test data analysis and evaluation of results.)
  – Understanding resource and facility limitations is critical to test design. Each resource/facility brings its inherent errors, limitations, and assumptions into the test architecture. These errors, limitations, and assumptions must be identified and managed in the test design to avoid problems with increased data variance and/or decreased test validity. Verification and validation (V&V) of the players and the architecture are essential. (Again, this is not unique to ADS test environment designs. However, it is more important that these limitations are known up front to ensure that the best quality environment is created. Connecting facilities tends to highlight their limitations.)
  – The TSLA specifications discuss the requirement for additional types of quality assurance instrumentation to monitor the environment representation at each location. Subtle differences in the waveform representations among locations have the potential to change how each player behaves in the scenario and may impact the test measures.

- The reliability of each test architecture component, resource, or facility has to be factored into the test design. The expected reliability of an ADS architecture is the product of the expected reliability of each component, resource, and facility. As such, reliability is expected to decrease as the number of components or players increase.
- OAR threats to be included in a synthetic environment require target, electronic countermeasures (ECM), and clutter signal injection capabilities. These capabilities are necessary for the threats to react correctly to synthetic players. OAR threats are necessary because of the limited number of manned threat simulators available in HITLs and ISTFs. Executing EW testing using the OSD EW test process is already limited by the availability of suitable simulators and environment representations in HITLs and ISTFs. [4]

- **ADS-Related Constraints**

  - Latency is a limitation on how tightly two players can be coupled. The Phase 2 DSM and Phase 3 ISTF architectures were capable of average round-trip transmission latency for HLA "reliable" (transmission control protocol [TCP]/Internet protocol [IP]) interactions of 254 and 167 milliseconds respectively. "Best effort" (user datagram protocol [UDP] multicast) latency was considerably better, and the architecture could have supported round-trip transmission latency of less than 100 milliseconds if JADS had used this protocol.
  - Commercial telecommunications technology and computer communications protocols used by JADS (as well as DIS and HLA) do not support the transmission of native spectrum environment data. Techniques currently used for transmitting analog electromagnetic waves in local distributed simulation facilities such as RF waveguide and fiber optic links are not affordable for geographically separated facilities. While analog waveforms can be captured digitally and transmitted over commercial telecommunications lines using computer communications protocols, they can use considerable bandwidth. JADS did not find bandwidth to be an issue. However, if entire digitized waveforms are being transmitted, bandwidth will quickly become an issue.
  - Data loss must be addressed in test design. JADS lost far less than 1% of data transmitted, however data loss depends on several factors. JADS EW Test showed that the lowest latency computer communications protocol consistently showed the highest data loss. Data loss impacts can be reduced by using error correction such as dead reckoning to replace data missing from a TSPI stream. Event data can not be predicted. Instead, event data must be either sent using more reliable but higher latency computer communications protocols, transmitted multiple times, transmitted with periodic data from the same player, or event data losses must simply be accepted.

[4]The JADS experience indicates that the Air Force test process described in Air Force Manual (AFMAN) 99-112, *Electronic Warfare Test and Evaluation Process Direction and Methodology for EW Testing*, is likely not executable with Air Force EW test resources. Shortfalls include HITL threat representations for all likely threats of interest and limited ISTF threat representations. Including the use of Navy facilities may ease the ISTF limitations. This is a significant issue for Air Force EW testing and for implementation of ADS-based testing. Closing and relocating the sole Air Force high fidelity threat simulator HITL as recommended in the Air Force's 1996 Electronic Combat Master Plan and reiterated in the 1999 DRMD 912 Congressional Report is likely to reduce the Air Force's ability to execute AFMAN 99-12.

- Out-of-order data are another ADS effect that must be addressed in test design. Differences in transmission methods, differences in distance, and the one-device-at-a-time nature of some computer communications protocols are all contributing factors. Designers need to be aware of the sources and deal with them in the design of the test architecture, data collection, and data analysis.

There are concerns which must be addressed for the proper implementation of ADS.

- The cost of implementing ADS. JADS found the single largest cost for implementing ADS to be the cost of modifications to facilities to allow them to connect. This cost may be significant (e.g., about $2 million for the EW SPJ test). Early testing against HITL threats is likely to increase cost over the current OSD EW test process design. However, early testing against HITL threats should uncover problems earlier in the development cycle. Ultimately, increased costs will have to be weighed against the improved test realism benefit, the potential improvements in test capability through combining facilities, and the potential of cost avoidance.
- Use of dedicated links. The use of dedicated leased telecommunications lines may be justified, rather than using existing networks such as Defense Simulation Internet (DSI), because of latency, reliability, and scheduling requirements. Each linking application must evaluate its requirements and justify the use of commercial links when appropriate. (Reference 2)

There are cultural and business practice concerns that must be addressed for the proper implementation of ADS.

- Segments of the EW community do not accept ADS as a "valid" way to test because it does not conform to the traditional approach. The JADS SPJ test lacked the complexity to convince many in this group. Others have not heard about the SPJ test despite JADS attempts to reach the community. As a result, select EW test facilities are driving the demand and advances in ADS-based testing and test design. Some of these facilities have been more successful in their attempts at implementing ADS than others. However, the EW system designers and testers are largely silent and are not placing requirements for ADS-based testing on the test facilities. This last observation is based on JADS interactions with selected Air Force and Navy test facilities and interactions with EW development and test organizations.
- Facilities are challenged when implementing ADS-based tests. Most existing facilities were designed to perform stand-alone tests. Facility details such as the ability to time synchronize the entire facility and internal latencies that are not a factor in traditional tests are critical in ADS-based tests. This forces facilities to investigate design details that may have been made decades earlier, and it forces facilities to reveal more of their internal workings than they are accustomed to revealing.
- ADS testing requires skills not found in traditional testing. Nontraditional skills include wide area computer network design, integration, test, and operation; local area computer network/wide area computer network integration and optimization; computer/simulation interface design, integration, optimization, and test; and if HLA is used,

RTI/computer/local area network/wide area network installation, optimization, and operation.

A number of methodologies apply for ADS implementation. These are discussed in JADS special reports and are simply listed here.

- Test planning (including cost benefit analysis)
- ADS architecture and instrumentation design
- Verification and validation (V&V) of the ADS configuration
- Integration of linked assets
- Test control

4.0 ADS Applicability to T&E of Specific EW Types

4.1 ADS Applicability Assessment Approach

Generalizing the results of the JADS EW Test to all possible EW systems operating in all possible environments is difficult. The JADS experience with an airborne self-protection jammer is limited when compared with all the possible types and operational spectra of EW systems. JADS gained direct experience with only four EW test facilities. While the TSLA survey provided a larger experience base, it was limited to RF and several political decisions have significantly changed the test infrastructure base to support EW testing. Additionally, several facilities are planning or executing upgrades. Therefore, the following is an extrapolation based on the JADS results.

JADS elected to assess applicability of ADS testing to specific EW functions by examining the nature of the test objective with respect to the interaction of the EW function with the threat. Air Force Manual 99-112, *Electronic Warfare Test and Evaluation Process – Direction and Methodology for EW Testing,* identifies two types of interactions between the EW function/device with the threat. The first interaction is "closed loop." Closed-loop testing is defined as "A form of EW testing in which both the friendly and threat systems react to each other's actions." While many "loops" can be closed in an EW test within the EW system or host platform, this definition highlights the interaction of the EW system with the threat. RF jammers are the best example of an EW function that is tested in a closed loop. The second interaction is "open loop." Open-loop testing is defined as "A test scenario in which a system reacts to another's actions without resulting feedback." EW receivers are the best example of an EW function that is tested open loop. RF jammers can be tested open loop to verify specification compliance. Jammer response time, percent correct response, and frequency accuracy are all examples of measures that can be collected in open-loop testing. However, jammer effectiveness measures such as tracking error and miss distance require closed-loop tests. Focusing on the nature of the device interaction highlights the benefits and limitations of ADS testing for a class of devices without addressing technical details of the test or SUT.

The distinction between open-loop and closed-loop testing in an ADS environment has significant impact on the architecture and test design. Closed-loop tests are more susceptible to latency which, in turn, limits the actions that can be taken to address data loss and out-of-order data. However, closed-loop tests are essential to understand the effectiveness of RF jammers.

While the open-loop/closed-loop distinction between EW tests is important, further distinctions are needed to understand the advantages and limitations of ADS-based testing for EW. JADS selected three representations of the SUT to examine where ADS may be advantageously applied. These representations are (1) DSM, (2) uninstalled hardware (breadboard, brassboard, final hardware traditionally tested in SILs and HITLs), and (3) installed hardware (hardware integrated in either a test bed platform or an instrumented version of the target platform traditionally tested in ISTFs or on OARs). These representations cover the entire range of SUT maturity during development.

This approach was selected to emphasize the application of ADS to testing EW systems without focusing on the specific function or functions of the device, the spectrum of the device, or the platform hosting the device. Specific EW functions were examined to ensure that the approach accurately addressed the benefits of using ADS-based testing. EW functions examined included warning receivers (RF and directed energy), intelligence receivers (RF and directed energy), jammers (self-protection RF and non-RF, standoff RF and non-RF, and communications), countermeasure dispensers, offboard countermeasures (chaff, flares, smoke, other decoys). JADS noted that single function devices were different than systems that integrated multiple functions. These are addressed separately in Table 1. Similarly platforms had to be investigated to ensure that the results remained valid. Platforms examined include aircraft, ground vehicles, surface vessels, submarines, and satellites. While not all facilities were used for all types of platforms (there are no indoor installed system test facilities for Navy ships, for example) the discussion is sufficiently broad to allow the reader to apply these results.

4.2 ADS Applicability Assessment Results

Table 1 summarizes JADS assessment of ADS benefits and the utility of ADS for open-loop single function devices; open-loop integrated EW systems; closed-loop, single-function devices; and closed-loop integrated EW systems in all development configurations from DSM through breadboard and brassboard to installed equipment. All benefits assume that the designer has accomplished an analysis of player interactions, has identified those interactions that least tolerate latency and has determined that an architecture can be constructed that can meet the latency requirement.

Table 1. ADS Applicability Assessment Results

Test Objective Type	EW System Type	Current DoD Test Process Facility	ADS Benefits	Utility Assessment
Open Loop	Single Device DSM	None	Limited. - Model-on-model interactions should be capable of generating the correct environment. (No investigation of model suitability was made.) - Real-time DSMs may allow dissimilar alternatives to be directly compared during analysis of alternatives phase of development.	Benefits are not expected to overcome cost of ADS for this application.
	Single Device Uninstalled	SIL, HITL	Limited. - Local stimulators should have the ability to generate the correct environment or the SUT is untestable at that location. - ADS adds the ability to remotely control some players.	Benefits are not expected to overcome cost of ADS for this application.
	Single Device Installed	ISTF, OAR	Limited. - Local stimulators should have the ability to generate the correct environment or the SUT is untestable at that location. - ADS adds the ability to remotely control some players.	Benefits are not expected to overcome cost of ADS for this application.
	Integrated EW System DSM	None	Moderate. - Model-on-model interactions should be capable of generating the correct environment. (No investigation of model suitability was made.) - Real-time DSMs facilitate operator interactions in model-on-model efforts. Useful if models can be reactive. - Real-time DSMs may allow dissimilar alternatives to be directly compared during analysis of alternatives phase of development.	Benefits may offset the cost of ADS architecture and real-time DSM development.

Test Objective Type	**EW System Type**	**Current DoD Test Process Facility**	**ADS Benefits**	**Utility Assessment**
	Integrated EW System Uninstalled	SIL, HITL (Testing must place all sensors in the same environment at the same time.)	Limited to Significant. - Limited benefit if all required stimulators are local and can present the same environment at the same time. - If all stimulators are not local, testing may be accomplished by testing the system sequentially in different facilities. - ADS can provide a common test environment to all sensors simultaneously (within the latency capability of the architecture). - ADS may be less expensive than facility upgrades. - ADS may save schedule over sequential testing.	Benefits should overcome cost of ADS architecture when all stimulators are not contained in a single facility.
	Integrated EW System Installed	ISTF, OAR (Testing must place the platform functions, all sensors, and all platform operators in the same environment at the same time.)	Limited to Significant. - Limited benefit if all required stimulators, operator interfaces, and platform functions are local and can present the same environment at the same time. - If all stimulators, operator interfaces, and platform functions are not local, testing may be accomplished by testing the system sequentially in different facilities. However, this limits testing to nonreactive scenarios. - ADS can provide a common test environment to all sensors, operators, and platform functions simultaneously (within the latency capability of the architecture). - ADS allows reactive test scenarios (within the latency capability of the architecture). - ADS may be less expensive than facility upgrades. - ADS may save schedule over sequential testing.	ADS has significant benefits if a single facility can't create the needed environment.

Test Objective Type	EW System Type	Current DoD Test Process Facility	ADS Benefits	Utility Assessment
Closed Loop	Single Device DSM	None	Moderate. - ADS provides the potential for reactive manned threats to interact with the DSM. Reactive manned threats allow system effectiveness to be evaluated. - Real-time DSMs may allow dissimilar alternatives to be directly compared during analysis of alternatives phase of development.	Benefits may offset the cost of ADS architecture.
	Single Device Uninstalled	SIL, HITL	Moderate. - Local stimulators should have the ability to generate the correct environment or the SUT is untestable at that location. - ADS adds the potential ability to link hardware installed in one facility to interact with manned threat simulators for effectiveness testing and/or with human platform operator(s) to allow more reactive and operationally realistic testing. - ADS may facilitate closed-loop effectiveness testing before hardware is in an easily transported configuration. - ADS potentially reduces time to correct problems by leaving the SUT in its development environment.	Benefits may offset the cost of ADS architecture.

Test Objective Type	EW System Type	Current DoD Test Process Facility	ADS Benefits	Utility Assessment
	Single Device Installed	ISTF, OAR	Moderate. - Local stimulators should have the ability to generate the correct environment or the SUT is untestable at that location. - ADS adds the potential ability to link hardware installed in one facility to interact with manned threat simulators for effectiveness testing and/or with human platform operator(s) to allow more reactive and operationally realistic testing. - ADS may allow concurrent electromagnetic compatibility/interference testing and effectiveness testing reducing the risk of executing sequential tests. - ADS potentially allows training assets to be used to increase signal density. -ADS potentially allows OAR emitter only threats to use closed-loop representations of the same threat at other facilities to increase closed-loop threat density. - ADS potentially allows real-time, high fidelity flyout of semi-active missiles with OAR track loop errors.	Benefits may offset the cost of ADS architecture.
	Integrated EW System DSM	None	Moderate. - ADS provides the potential for reactive manned threats to interact with the DSM. Reactive manned threats allow system effectiveness to be evaluated. - Real-time DSMs may allow dissimilar alternatives to be directly compared during analysis of alternatives phase of development.	Benefits may offset the cost of ADS architecture.

Test Objective Type	**EW System Type**	**Current DoD Test Process Facility**	**ADS Benefits**	**Utility Assessment**
	Integrated EW System Uninstalled	SIL, HITL (Testing must place all sensors in the same environment as manned threat simulators and all must interact.)	Limited to Significant. - Limited benefit if all required stimulators are local, can present the same environment at the same time, and include manned threat simulators. - If all stimulators and manned threat simulators are not local, testing may be accomplished by testing the system sequentially in different facilities, however risk increases and sequential testing significantly limits the reactive elements in the scenario. - ADS can provide a common test environment to all sensors simultaneously and manned threat simulators (within the latency capability of the architecture). - ADS may be less expensive than facility upgrades. - ADS may save schedule over sequential testing. - ADS may add significant realism to the scenario. - ADS may facilitate closed-loop effectiveness testing before hardware is in an easily transported configuration. - ADS potentially reduces time to correct problems by leaving the SUT in its development environment.	ADS has significant benefits if a single facility can't create the needed environment.

Test Objective Type	EW System Type	Current DoD Test Process Facility	ADS Benefits	Utility Assessment
	Integrated EW System Installed	ISTF, OAR (Testing must place the platform functions, all sensors, manned threat simulators and all platform operators in the same environment at the same time.)	Limited to Significant. - Limited benefit if all required stimulators, operator interfaces, and platform functions are local and can present the same environment at the same time. - If all stimulators, manned threat simulators and platform operators are not local, testing may be accomplished by testing the system sequentially in different facilities, however risk increases and sequential testing significantly limits the reactive elements in the scenario. - ADS can provide a common test environment to all sensors, operators, and platform functions simultaneously (within the latency capability of the architecture). - ADS allows reactive test scenarios (within the latency capability of the architecture). - ADS may be less expensive than facility upgrades. - ADS may save schedule over sequential testing. - ADS may allow concurrent electromagnetic compatibility/interference testing and effectiveness testing reducing the risk of executing sequential tests. - ADS potentially allows training assets to be used to increase signal density. -ADS potentially allows OAR emitter only threats to use closed-loop representations of the same threat at other facilities to increase closed-loop threat density. - ADS potentially allows real-time, high fidelity flyout of semi-active missiles with OAR track loop errors.	ADS has significant benefits if a single facility can't create the needed environment.

Table 1 was limited to EW devices and integrated system testing which cover testing one on one and one on few. EW devices are not limited to these types of engagements since the platforms they support are not generally deployed in single-ship formations. The effect on mission success of EW devices in operationally relevant multi-ship formations is equally important to understand. Likewise, providing the multi-ship formation with the electronic support measures (ESM) expected in combat is essential if the developer, tester, or user wants to fully understand the combined impact of all the EW systems involved in mission success. This is generally described as systems of systems testing.

ADS has utility for systems of systems testing since it provides affordable access to high fidelity manned simulations of additional players. (Reference 3) Traditional methods of evaluating systems of systems used either model-on-model evaluations or live player through exploitation of exercises or actual operations. All these approaches are limited. While simulators and linking technology are available today, they remain the limiting factor in systems of systems T&E. As initiatives such as Simulation Based Acquisition and HLA begin to bear fruit, the tester should have more raw materials available to create rich synthetic environments for ADS-based systems of systems T&E.

5.0 Summary

The findings from the JADS SPJ test coupled with the experience gleaned from the HLA EPF, TSLA, and ADEWS were extrapolated to EW systems other than the airborne SPJ. Distributed interactive simulations are already being used to test EW systems. Geographical distribution is a logical step in the evolution of EW testing, and several EW test facilities are experimenting in this area. ADS testing is not addressed in the DoD EW test process description; however, ADS can be useful to EW testing. It may provide a method for improving the validation of DSMs. It provides the opportunity to avoid sequential testing by combining the capabilities of different facilities. It provides an alternative to improving a facility to create a single environment for adequate testing of integrated EW systems. It may be the only way to affordably test systems of systems.

A more definitive statement on utility is not possible because of the inability to clearly identify cost savings and because the benefits of using ADS vary according to the type of system being tested. In general, the cost of this architecture is more likely to be recovered over the entire development cycle than it is in a single test event. All types of EW systems can be tested in some fashion using ADS. However, stand-alone EW functions are less likely than integrated EW systems to find the benefits worth the costs. The largest barrier to ADS testing in EW is the availability of linkable EW test infrastructure. However, the missing infrastructure already limits the amounts and types of traditional EW testing.

This report provides a general assessment of the usefulness of ADS testing for different EW system functions. Detailed requirements were not developed, however the TSLA study provides more information on message sizes and rates. Also, some characteristics of specific EW systems may have been overlooked, which could impact the ADS design and feasibility of implementation. The extrapolation of JADS EW Test results to EW system functions was based on informed conjecture without rigorous analysis or supporting data. Applications were assumed to be feasible unless there was evidence to the contrary.

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Appendix A - List of Acronyms

ACETEF	Air Combat Environment Test and Evaluation Facility, Patuxent River, Maryland; Navy facility
ADEWS	Advanced Distributed Electronic Warfare System; Army sponsored
ADS	advanced distributed simulation
AFEWES	Air Force Electronic Warfare Evaluation Simulator, Fort Worth, Texas
AFMAN	Air Force manual
AFOTEC	Air Force Operational Test and Evaluation Center, Kirtland Air Force Base, New Mexico
ALQ-131	a mature self-protection jammer system; an electronic countermeasures system with reprogrammable processor developed by Georgia Tech Research Institute
ARPA	Advanced Research Projects Agency
ATEWES	Advanced Tactical Electronic Warfare Environment Simulator
C4I	command, control, communications, computers and intelligence
C4ISR	command, control, communications, computers, intelligence, surveillance and reconnaissance
COMM	communications
COTS	commercial off-the-shelf
CREWS	Covert Remote Electronic Warfare System
CROSSBOW	Office of the Secretary of Defense committee under the Director, Test Systems Engineering and Evaluation
DIS	distributed interactive simulation
DMSO	Defense Modeling and Simulation Organization, Alexandria, Virginia
DoD	Department of Defense
DSI	Defense Simulation Internet
DSM	digital system model
DT&E	developmental test and evaluation
ECM	electronic countermeasures
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EO	electro-optical
EPF	engineering protofederation
ES	entity state; electronic support
ESM	electronic support measures
ETE	JADS End-to-End Test
EW	electronic warfare
FEDEP	federation development and execution process
GPS	global positioning system
HITL	hardware-in-the-loop
HLA	high level architecture
IADS	Integrated Air Defense System
ICD	interface control document

IEEE	Institute of Electrical and Electronics Engineers
IP	initial point; Internet protocol
IR	infrared
ISTF	installed systems test facility
JADS	Joint Advanced Distributed Simulation, Albuquerque, New Mexico
JETS	JammEr Techniques Simulator
JMASS	Joint Modeling and Simulation System
Joint STARS	Joint Surveillance Target Attack Radar System
JT&E	joint test and evaluation
JTF	joint test force
MIL	military
MITRE	company that provides engineering services
MOE	measures of effectiveness
MOP	measures of performance
OAR	open air range
OMDT	object model development tool
OSD	Office of the Secretary of Defense
OT&E	operational test and evaluation
RCS	radar cross section
RF	radio frequency
RTI	runtime infrastructure
SAR	synthetic aperture radar
SIL	system integration laboratory; system-in-the-loop
SIMNET	simulator network
SIT	JADS System Integration Test
SPJ	self-protection jammer
SUT	system under test
SWEG	Simulated Warfare Environment Generator at Air Combat Environment Test and Evaluation Facility, Patuxent River, Maryland
T&E	test and evaluation
T-1	digital carrier used to transmit a formatted digital signal at 1.544 megabits per second
TCP	transmission control protocol
TSLA	Threat Simulator Linking Activity
TSPI	time-space-position information
UDP	user datagram protocol
V&V	verification and validation
VV&A	verification, validation and accreditation

Appendix B - Kaminski Memorandum
Directing Implementation of HLA for DoD Simulations

Under Secretary of Defense
(Acquisition and Technology)

Sept. 10, 1996

MEMORANDUM FOR:	SECRETARIES OF THE MILITARY DEPARTMENTS CHAIRMAN OF THE JOINT CHIEFS OF STAFF UNDER SECRETARIES OF DEFENSE ASSISTANT SECRETARIES OF DEFENSE GENERAL COUNCIL OF THE DEPARTMENT OF DEFENSE INSPECTOR GENERAL OF THE DEPARTMENT OF DEFENSE DIRECTOR, OPERATIONAL TEST AND EVALUATION ASSISTANTS TO THE SECRETARY OF DEFENSE DIRECTOR OF ADMINISTRATION AND MANAGEMENT DIRECTORS OF THE DEFENSE AGENCIES
SUBJECT:	DoD High Level Architecture (HLA) for Simulations
References:	a. DoD Directive 5000.59, "DoD Modeling and Simulation (M&S) Management," January 4, 1994 b. DoD 5000.59-P, "DoD Modeling and Simulation Master Plan (MSMP)," October 1995

Under the authority of reference (a), and as prescribed by reference (b), I designate the High Level Architecture as the standard technical architecture for all DoD simulations.

The baseline HLA is defined by three inter-related elements: HLA Rules Version 1.0 (v.1.0), HLA Interface Specification v.1.0, and HLA Object Model Template v.1.0. The evolution of the HLA will be managed by the DoD Executive Council for Modeling and Simulation (EXCIMS) through its Architecture Management Group (AMG). This structure provides a means for the DoD Components to identify and address any emergent issues in subsequent refinements to the HLA. Compliance with the HLA does not mandate the use of any particular implementation of supporting software such as the Runtime Infrastructure.

DoD Components shall review all of their simulation projects and programs by the second quarter fiscal year (FY) 1997 in order to establish plans for near-term compliance with the HLA. The Department shall cease further development or modification of all simulations which have not achieved, or are not in the process of achieving, HLA-compliance by the first day of FY 1999, and shall retire any non-compliant simulations by the first day of FY 2001. EXCIMS is to monitor progress and advise me if any emergent events affect their viability.

To monitor compliance with the HLA, the DoD Components shall submit an initial report to the

Defense Modeling and Simulation Office (DMSO) by June 30, 1997, which summarizes their HLA-compliance intentions for each simulation the Component owns or sponsors, organized into three categories:

- HLA-compliance actions initiated immediately
- HLA-compliance actions initiated at a specified future date
- no HLA compliance planned (thus requiring eventual retirement or a waiver)

The DoD Components shall submit periodic updates to these initial reports as required to ensure their accuracy and completeness. DMSO shall establish a mechanism to provide for formal certification of compliance and shall provide me with periodic reports on the Department's progress towards compliance with the HLA.

If a Component believes it is impractical for a simulation to comply with the HLA, or that HLA-compliance cannot be achieved in a timely manner, it may submit a waiver request to the Director of Defense Research and Engineering, the Chair of the EXCIMS. In consultation with the EXCIMS and its Training, Analysis, and Acquisition Councils, I will then decide if an exception to the HLA-compliance requirement is warranted, and if so, the form of that exception.

This mandate for HLA-compliance supersedes all previous requirements for DoD simulations to comply with other simulation standards such as Distributed Interactive Simulation or Aggregate-Level Simulation Protocol. It is expected that new industry standards to support the HLA will emerge. In consultation with the EXCIMS and its AMG, I will evaluate the suitability of such standards for the Department as they are established.

The DoD point of contact for the HLA is the Defense Modeling and Simulation Office at (703) 998-0660 or hla@dmso.mil. The HLA documents are available at http://www.dmso.mil/.

\original signed\
Paul G. Kaminski

Appendix C - Simple ADS Concept Model

The following discussion presents a general concept model intended to provide those unfamiliar with Joint Advanced Distributed Simulation (JADS) with a simple frame of reference for understanding where distributed testing can be inserted for enhancing test and evaluation (T&E) environments. Figure C1 illustrates the simplest representation of a weapon system or electronic warfare (EW) device. The sensor provides a representation of the outside world or environment to the processing function. The sensor may require some form of transmitted energy (the flashlight in the figure) to illuminate the environment for the sensor. The processor acts on the information provided by the sensor and, if appropriate, takes some action that ultimately changes the environment.

The sensor can be an actual radio frequency (RF) sensor (as in the case of a radar warning receiver, an intelligence receiver, a data link, etc.), a non-RF sensor (ultraviolet, infrared, a laser detector, etc.), or it may simply be the interface to the platform's internal communications bus as in the case of a simple expendables dispenser. Illumination for the sensor can be RF, electro-optical (OE)/infrared (IR), coherent or incoherent. However, the illuminator is controlled by the processor. Its contribution to the environment would not be expected to be present unless the device is present. The sensor may or may not require an illuminator. The processor can be hardware, human or both depending on how the test designer chooses to model the system. It is a mechanism that maps sensor information into some response. Responses are quite varied. Responses include cueing the operator, automatic course change, a track file hand-off to another onboard system, information hand-off to another platform, or a directed energy attack on the threat.

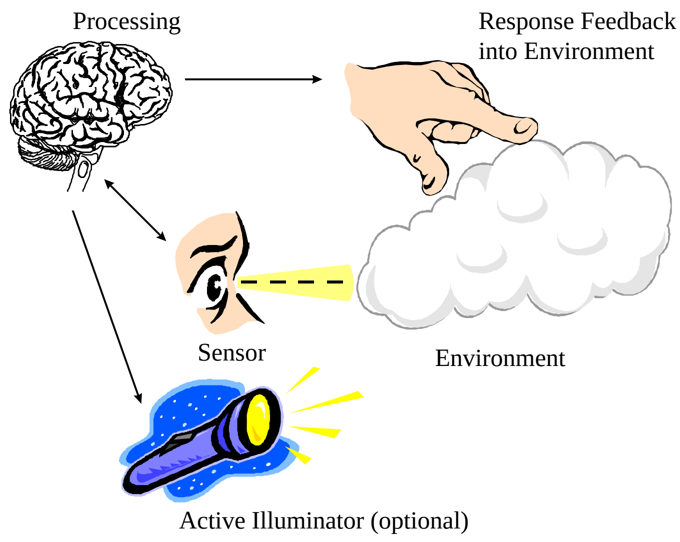
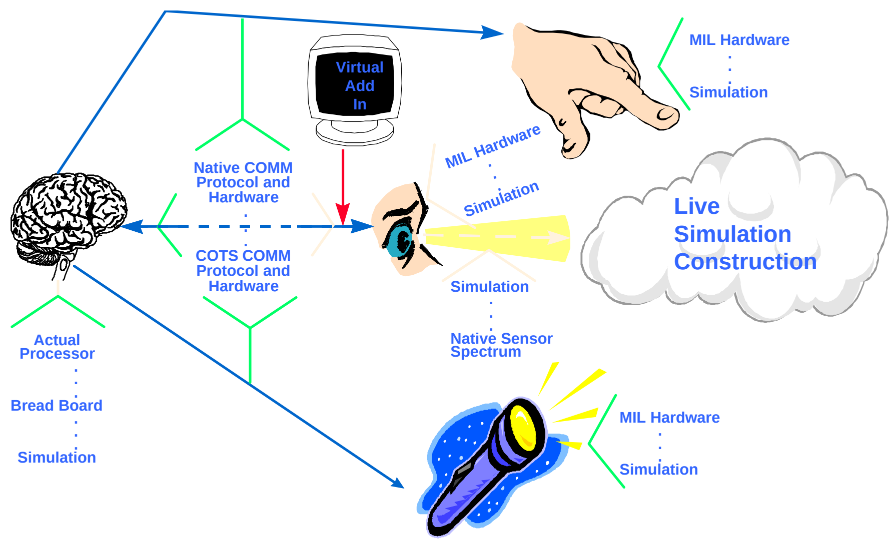


Figure C1. Simple System

Distributed simulation can be introduced into the system in several ways. First simulation can be used to supply the entire environment the sensor sees. A stimulator takes inputs from the simulation architecture and recreates it in a format the sensor can "see." This approach was used in the System Integration Test (SIT) where the environment seen by the missile was controlled by other players in the architecture. Next, simulation can be used to add information to a scene being observed by the sensor. Think of this as breaking into the communication path between the sensor and the brain to add features to the environment that are not really there. JADS used this approach in the End-to-End (ETE) Test where more than 10,000 entities were added to the synthetic aperture radar (SAR) scene. Finally, simulation can be used to insert the response into the environment being seen by another sensor. This was done in the EW Test where the jammer responses were injected into the RF environment seen by the threat systems. All three methods can be used in EW testing. This is shown in Figure C2.

It is important to note from the figure, the number of different possible representations of the sensor, processor, illuminator, and response. In distributed testing, each of these need not be the same maturity in order to be connected. For example, a military hardware processor can be connected to a digital simulation of the sensor. T&E will likely use the representation that makes sense for the test objective desired. This means that each of the communications paths will be built based on the representation of the two items the path is connecting. In the military hardware, digital simulation example above, the designer may use the military standard data bus that would normally connect the sensor and processor, or the designer may elect to use commercial computer communications hardware and protocols (e.g., Ethernet and transmission control protocol [TCP]/Internet protocol [IP]) and place an interface unit in front of the military hardware.



COMM = communications COTS = commercial off-the-shelf MIL = military

Figure C2. System Connection Points to Synthetic Environment

Figure C2 illustrates the different ways each player in an distributed interactive simulation might be linked to other players. Multiple players will need to be connected to create a test architecture. The challenge to the test designer is to step past the traditional hardware boundaries and divide the problem into functions that can be combined to realistically represent the players.

Distributed test facilities already address EW problems in this fashion.

The next challenge, once the functions are defined, is to find a facility or simulation that has the function(s) required. This is illustrated in the EW Test in several ways. The "aircraft" was composed of a radar cross section (RCS) database at the Air Force Electronic Warfare Evaluation Simulator (AFEWES) combined with a time-space-position information (TSPI) script played into the architecture from JADS. The Phase 3 jammer had two transmitter sets. The first was the pod's internal military hardware which radiated into the anechoic chamber at Air Combat Environment Test and Evaluation Facility (ACETEF) to simulate electromagnetic capability (EMC)/electromagnetic interference (EMI) testing. The second was a laboratory jammer technique generator/simulator, the JammEr Technique Simulator (JETS) at AFEWES. The JETS jamming waveforms were injected into the RF environment that the AFEWES threat simulators used. Similarly, the AFEWES threat simulators had two transmitters. The first was at AFEWES and it was used to "illuminate" the synthetic aircraft (RCS and TSPI) for the environment at AFEWES. The second was the Advanced Tactical Electronic Warfare Environment Simulator (ATEWS) equipment at ACETEF. This hardware generated the RF energy that was injected into the pod behind the antenna to create the environment for the pod.

It is important to realize that the environment at AFEWES was not the same as the environment seen by the pod. Latency differences placed the aircraft at slightly different locations in the two environments. JADS overcame this by taking all miss distance data from the AFEWES environment. There were other obvious differences. The aircraft fire control radar was not recreated in the AFEWES environment. During excursion runs, ACETEF used the Synthetic Warfare Environment Generator model (SWEG) to add two additional threats into the pod's environment. These were not recreated in the AFEWES environment either because of schedule constraints. The decision to add the extra threats was made one week before our verification/validation testing of the ACETEF federate and the architecture certification. The final difference was in the waveforms at each facility. Because the RF waveform was not digitized and transmitted, it was possible that there were waveform differences between the two facilities. Additional instrumentation was needed to record the actual RF environment at each facility during test, and the waveforms at each facility had to be examined closely and validated prior to validating the architecture.

Since the architecture did not transmit digitized waveforms, JADS had to find a way to communicate threat and pod state changes. JADS created simple brief messages to indicate state changes in the threat or the pod. Only these brief mode descriptions were transmitted between AFEWES and ACETEF. The actual RF was created at each site based on a common understanding of the mode descriptions. This is illustrated in Figure C3.

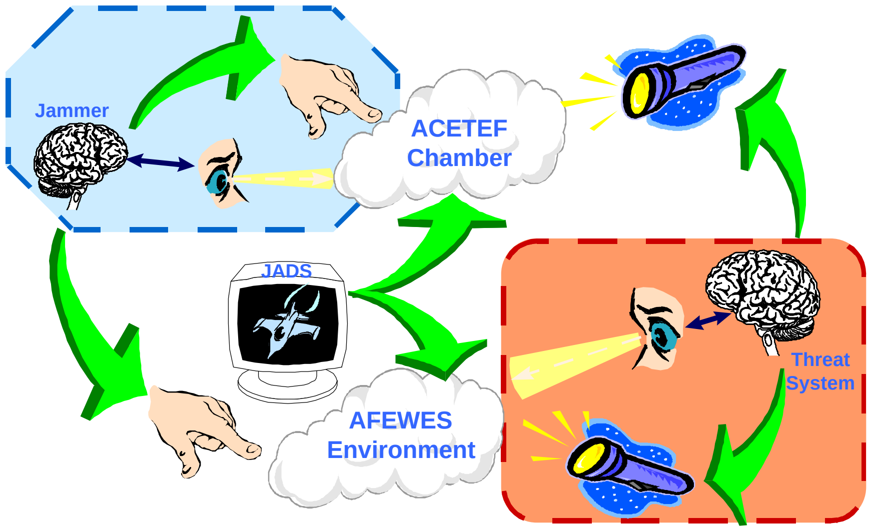


Figure C3. EW Test Architecture

This discussion is intended to start the test designer down the path of creating a distributed test. There are other tools needed to fully create and describe a useful test design methodology. The high level architecture (HLA) community is developing a set of processes and tools that will help test designers create distributed test architectures. These processes and tools need to be added to the organization's program management and system engineering processes to manage the risks involved in creating distributed simulation and distributed test architectures. The Federation Development Execution Process (FEDEP) describes the steps that designers must go through to create distributed simulation and distributed test environments. Several overlays such as security and verification, validation, and accreditation (VV&A) are being created to connect these processes to the FEDEP. The tools are directed primarily at HLA applications. These tools include the object model development tool (OMDT) (which describes the message formats, who creates the message, and who uses the message) and the Federation Execution Planners Workbook (which ties the messages to hardware within the architecture and allows issues such as latency and bandwidth to be addressed). These tools coupled with traditional systems and software engineering tools (such as interface control documents), system specifications, software requirement specifications, and configuration management tools) will help the designer build and execute a distributed test.